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# High Mass Dijet and ttbar Resonance Searches at the Tevatron

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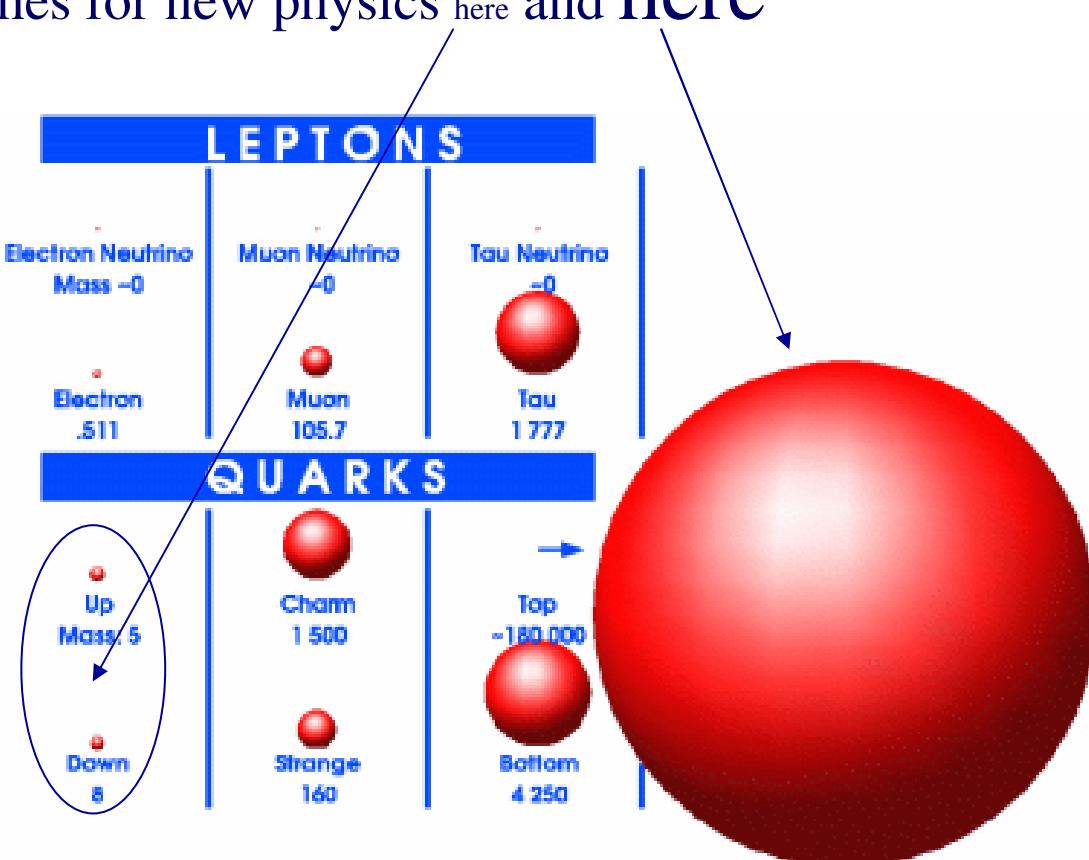
University of Mississippi

for the CDF and DØ Collaborations

ICHEP 2008, Philadelphia, USA

# Introduction

- At Tevatron we are looking for new physics in a large variety of final states produced in the proton-antiproton collisions
- This talk addresses searches for new physics [here](#) and [here](#)



# Overview

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## Dijet Final State

- Of all high PT processes at a hadron collider, QCD processes have the largest cross section  
⇒ well-measured shapes
- Good place to look for the deviations from the Standard Model predictions

## ttbar Final State

- the top quark may have a special connection with the Electroweak Symmetry Breaking and new physics
- By now we collected relatively large ttbar samples
- Look for new physics in the ttbar data

# List of Analyses Presented

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## Dijet Final State

- CDF dijet invariant mass spectrum,  $1.13 \text{ fb}^{-1}$  , note 9246
- DØ dijet angular distributions,  $1.1 \text{ fb}^{-1}$  , note 5733

## **ttbar Final State (lepton+jets channel)**

- DØ,  $2.1 \text{ fb}^{-1}$  , note 5600
- CDF, template method ,  $1 \text{ fb}^{-1}$ , PRD 77 051102
- CDF, matrix method + template ,  $680 \text{ pb}^{-1}$  , PRL 100 231801
- CDF, Dynamic Likelihood Method ,  $1.9 \text{ fb}^{-1}$  , note 9164

# Simulated Di-Jet Resonances from New Physics

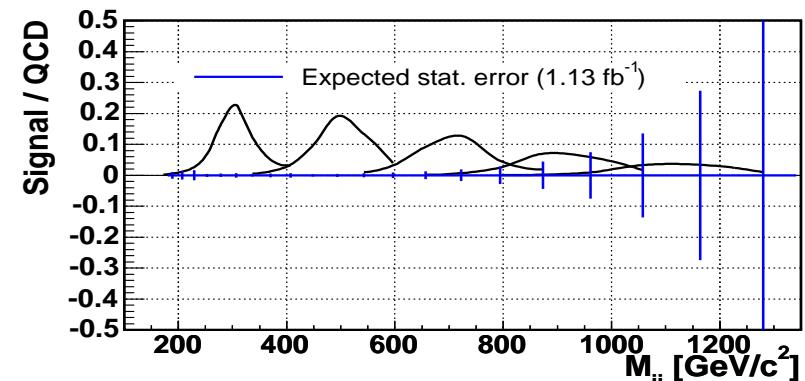
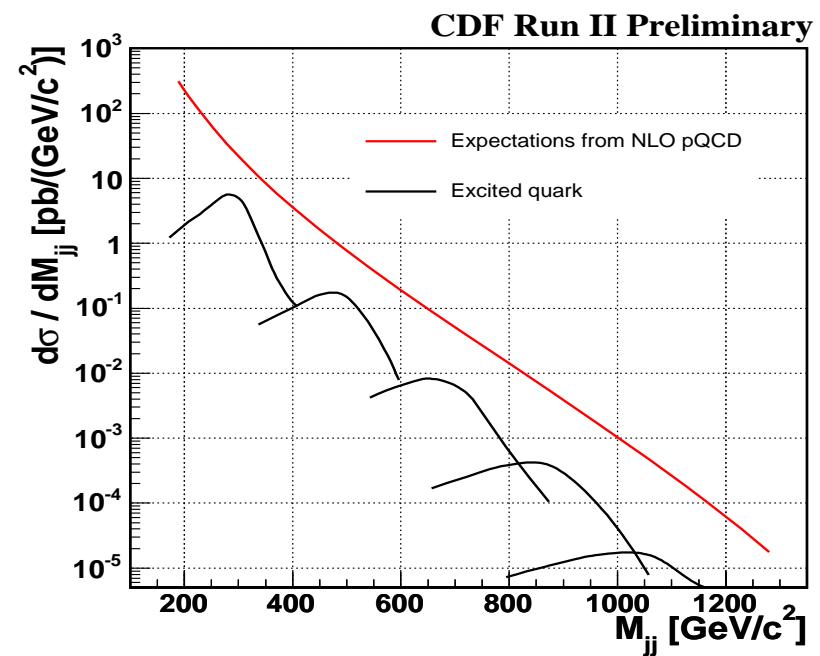
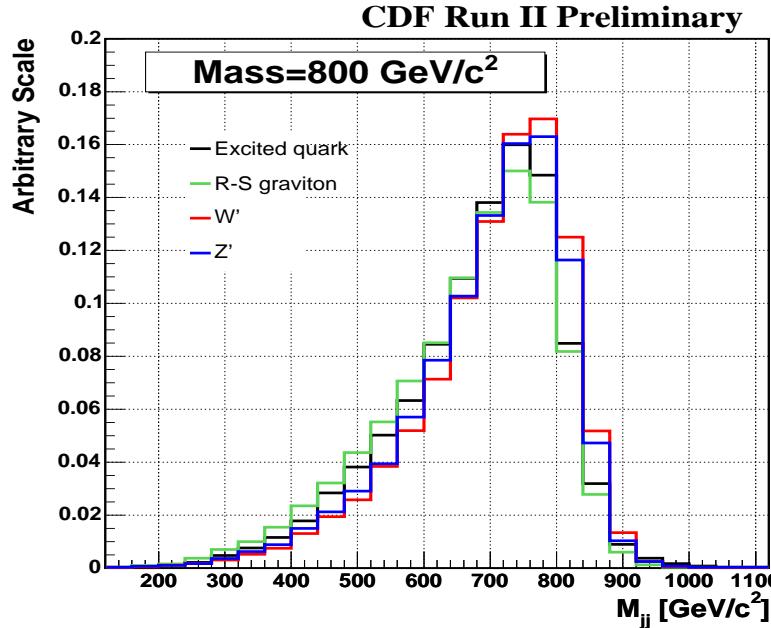
- Dijet distributions from four models that produce mass resonances

Excited quark

Randall-Sundrum graviton

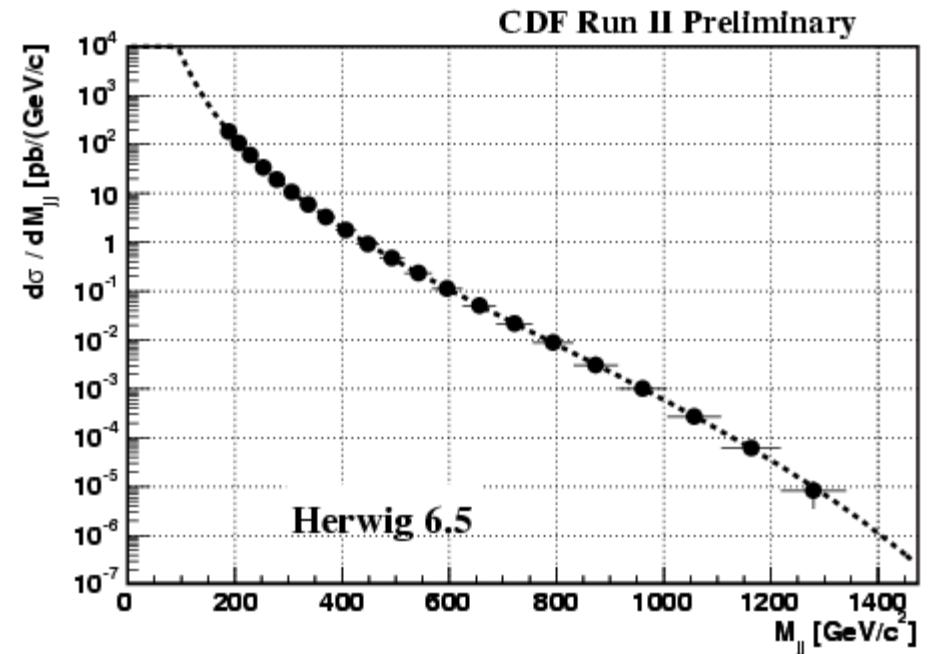
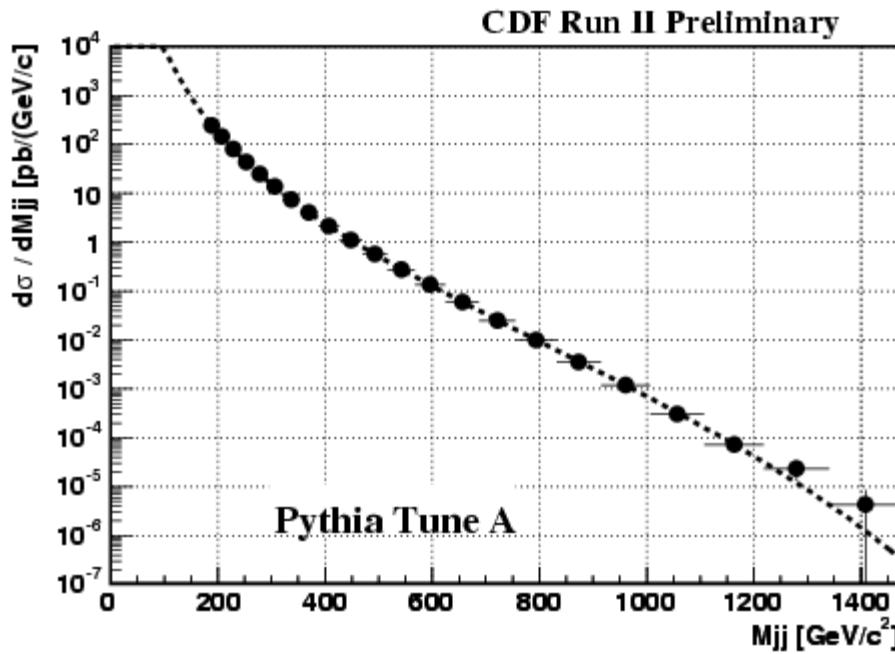
$W'$

$Z'$



# Modeling QCD Production

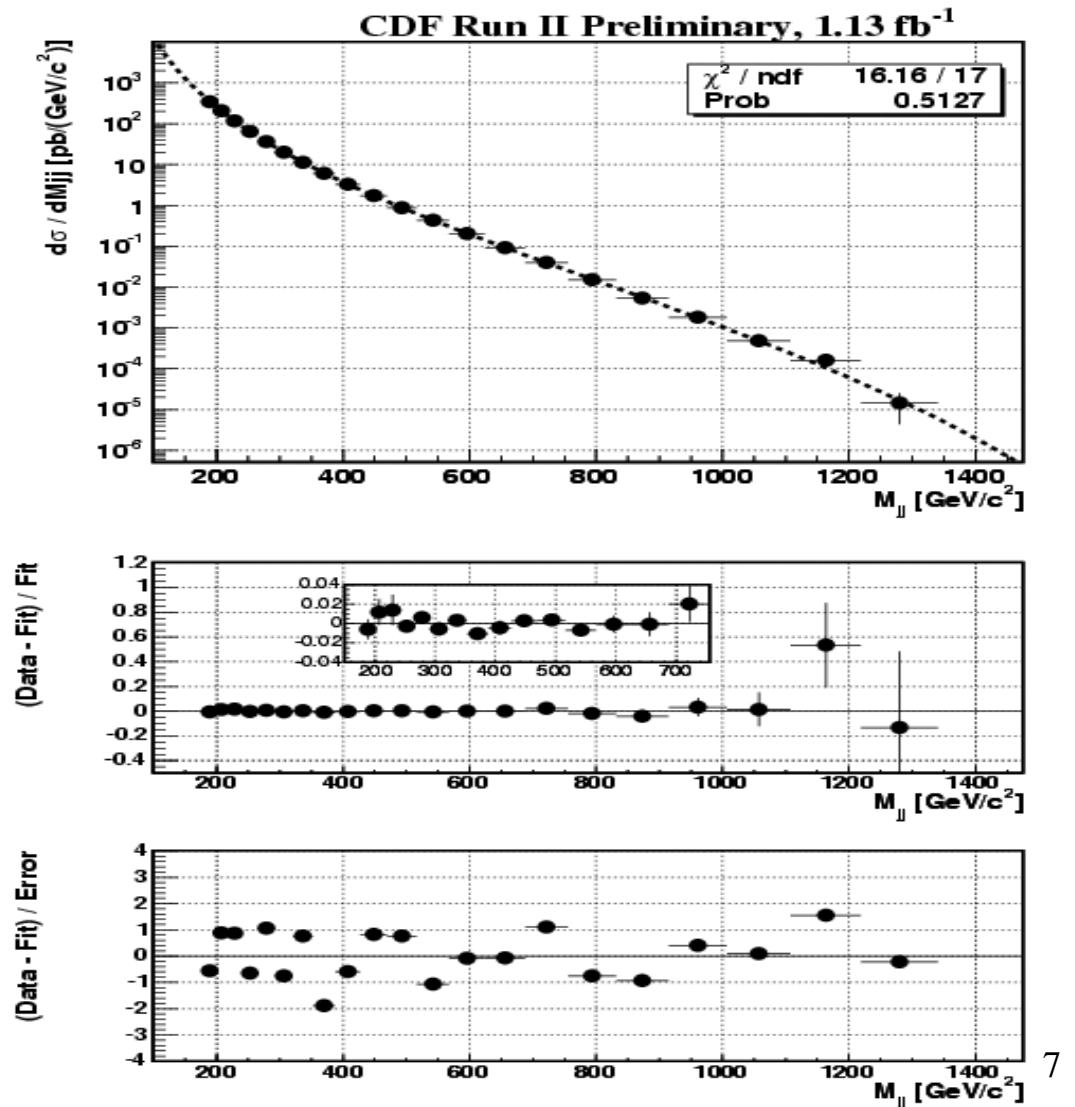
- dijet mass spectrum models from PYTHIA and HERWIG
- reconstructed-level distributions



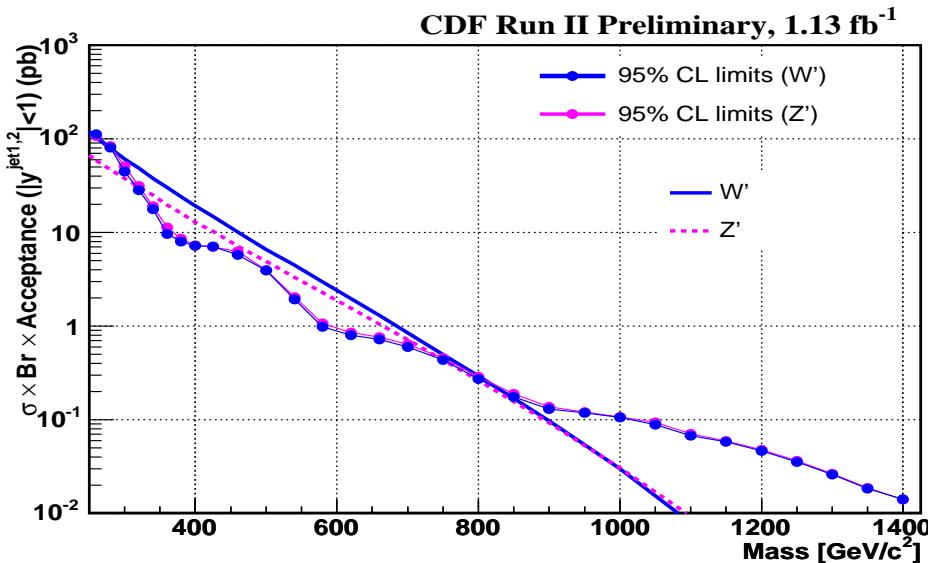
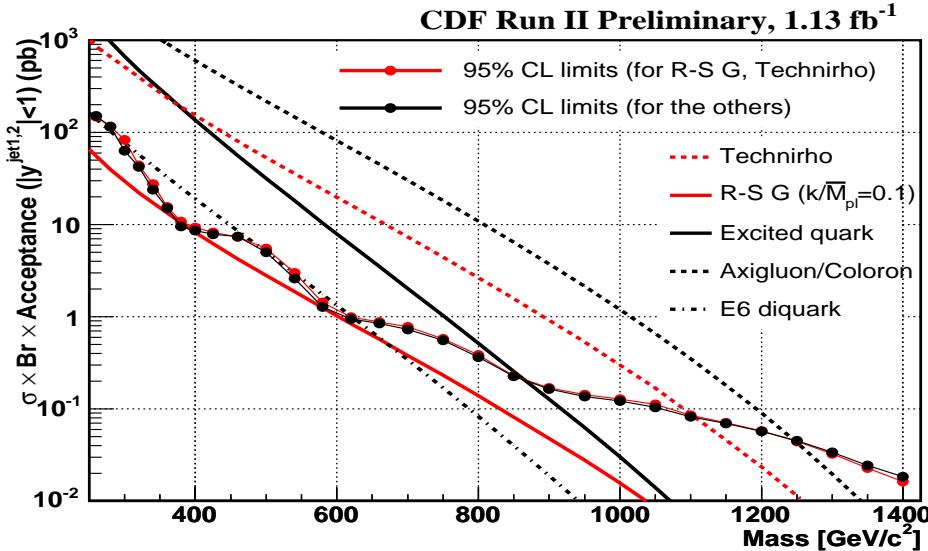
$$\frac{d\sigma}{dm} = p_0 (1-x)^{p_1} / x^{p_2 + p_3 \log(x)}, \quad x = m / \sqrt{s}$$

# Measured Dijet Data

- select jets within rapidity of 1.0
  - midpoint jet algorithm with cone 0.7
  - dijet masses above 180 GeV
  - remove cosmic events with Missing Et significance cut
- Fit dijet mass spectrum with the parameterized model shape
- No significant indication of resonant structure is observed
- Set limits using Bayesian approach



# Limits from CDF's Dijet Search



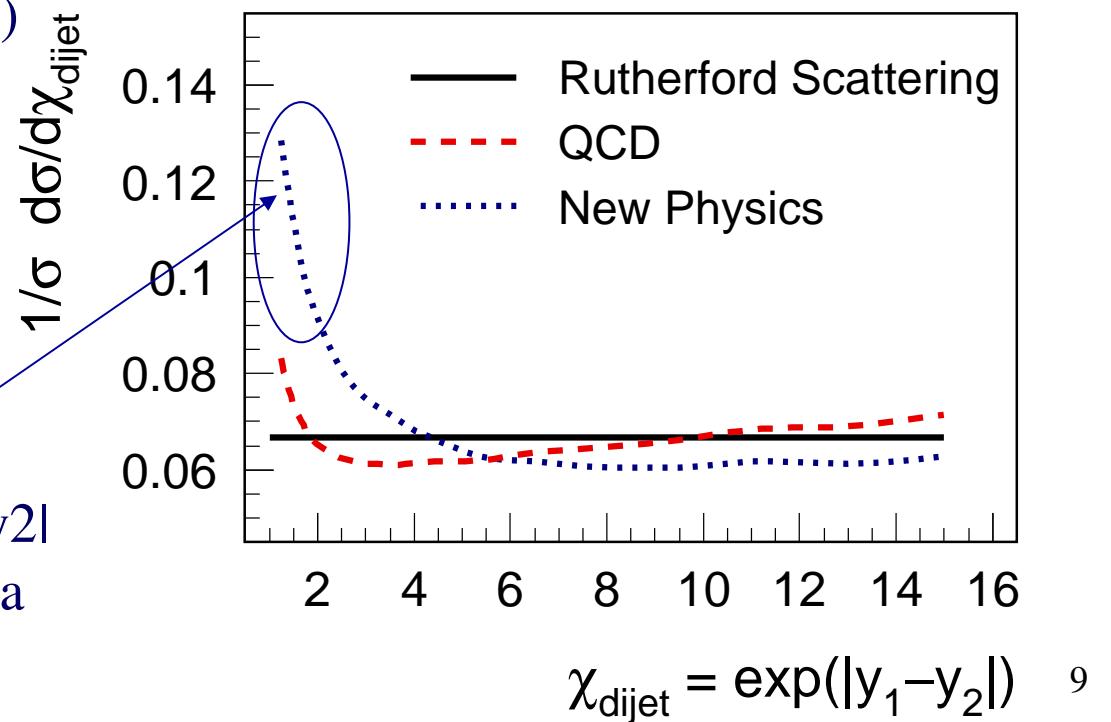
Observed mass exclusion range	Model description
<b>260-870 <math>\text{GeV}/c^2</math></b>	Excited quark ( $f=f'=fs=1$ )
<b>260-1100 <math>\text{GeV}/c^2</math></b>	Color-octet technirho [top-color-assisted-technicolor (TC2) couplings, $M'_8=0$ , $M(\pi_{22}^8)=5M(\rho)/6$ , $M(\pi_{22}^1)=M(\pi_{22}^8)/2$ , $M_8=5M(\rho)/6$ ]
<b>260-1250 <math>\text{GeV}/c^2</math></b>	Axigluon and flavor-universal coloron (mixing of two SU(3)'s, $\cot(\theta)=1$ )
<b>290-630 <math>\text{GeV}/c^2</math></b>	$E_6$ diquark
<b>280-840 <math>\text{GeV}/c^2</math></b>	$W'$ (SM couplings)
<b>320-740 <math>\text{GeV}/c^2</math></b>	$Z'$ (SM couplings)

most stringent limits except on  $Z', W'$ <sup>8</sup>

# DØ Dijet Angular Distribution

- Dijet angular distribution with respect to the beam direction is directly sensitive to the dynamics of the underlying reaction
- Use variable  $\chi_{\text{dijet}} = \exp(|y_1 - y_2|)$
- In the limit of massless  $2 \rightarrow 2$  scattering process  $\chi_{\text{dijet}}$  is directly related to the polar scattering angle  $\theta^*$  in the partonic center-of-mass frame  

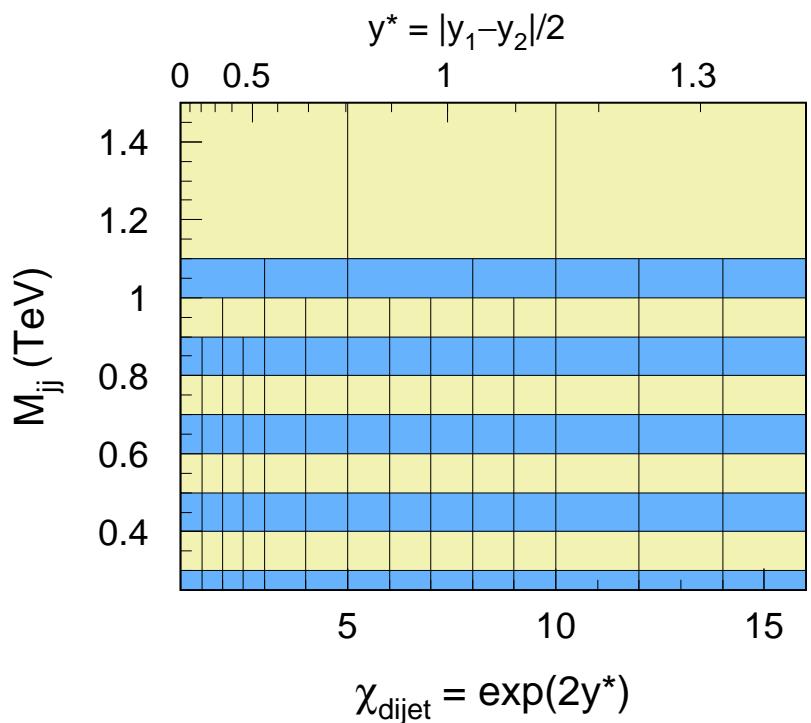
$$\chi_{\text{dijet}} = (1 + \cos \theta^*) / (1 - \cos \theta^*)$$
  - large values of  $\chi_{\text{dijet}}$   
 $\Rightarrow$  small scattering angles
  - small value of  $\chi_{\text{dijet}}$   
 $\Rightarrow$  scattering angle  $\rightarrow \pi/2$   
 (these are central events,  
 look for new physics here)
- Another variable  $y_{\text{boost}} = \frac{1}{2} |y_1 + y_2|$   
 is related to the ratio of momenta  
 of incoming partons



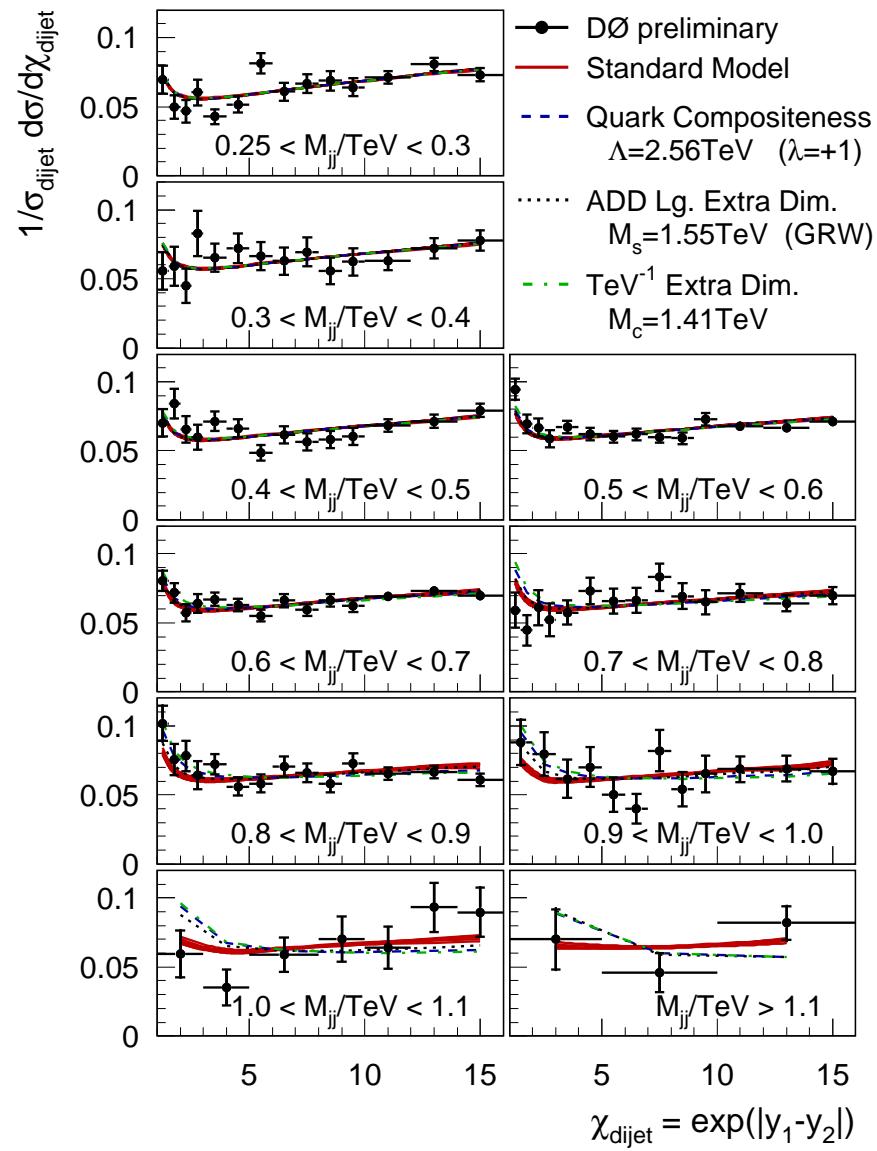
# DØ Dijet Angular Distribution

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- Trigger events with a single jet trigger
- Reconstruct jets with the RunII midpoint cone ( $R=0.7$ )
- Correct for instrumental effects
  - response,
  - resolution
  - out-of-cone showering,
  - additional energy
  - vertex mis-identification
  - jet reconstruction inefficiencies
- Arrive at “particle level” dijet distributions
- Split dijet invariant mass range into several sub-ranges

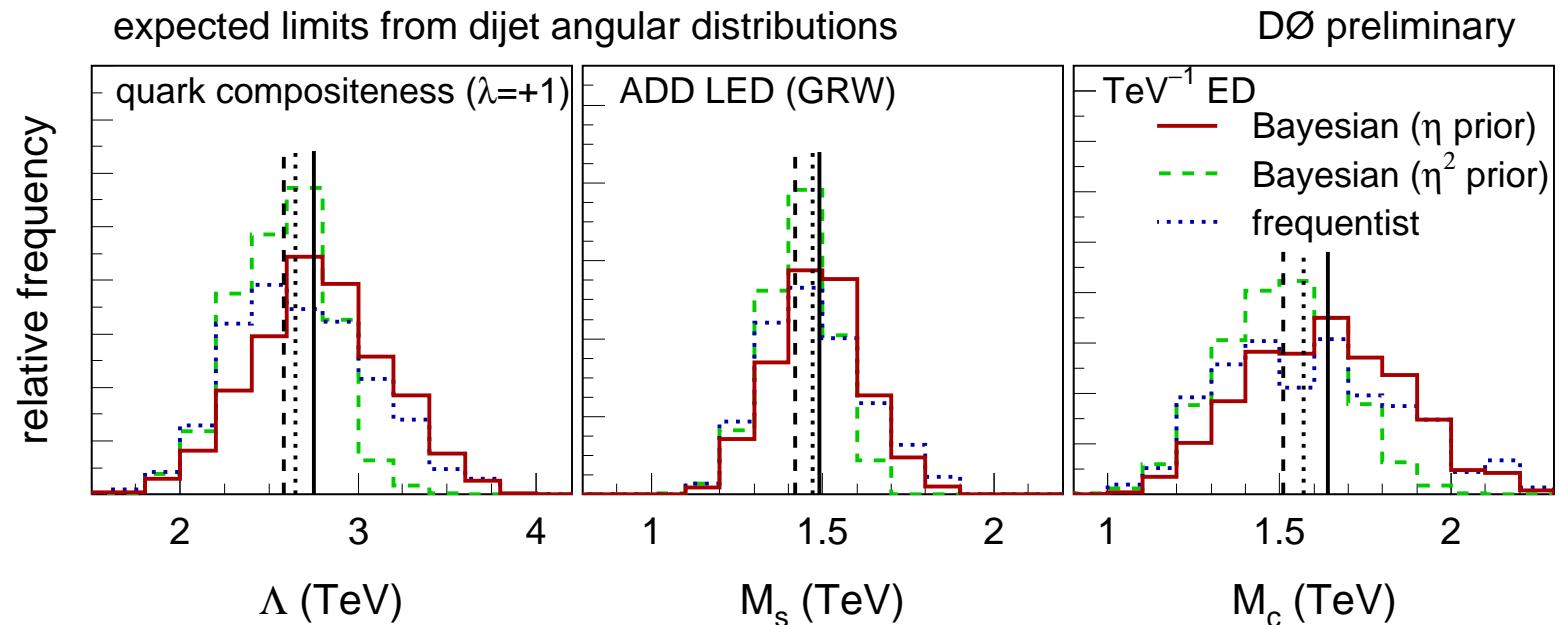


# Particle-Level Distributions

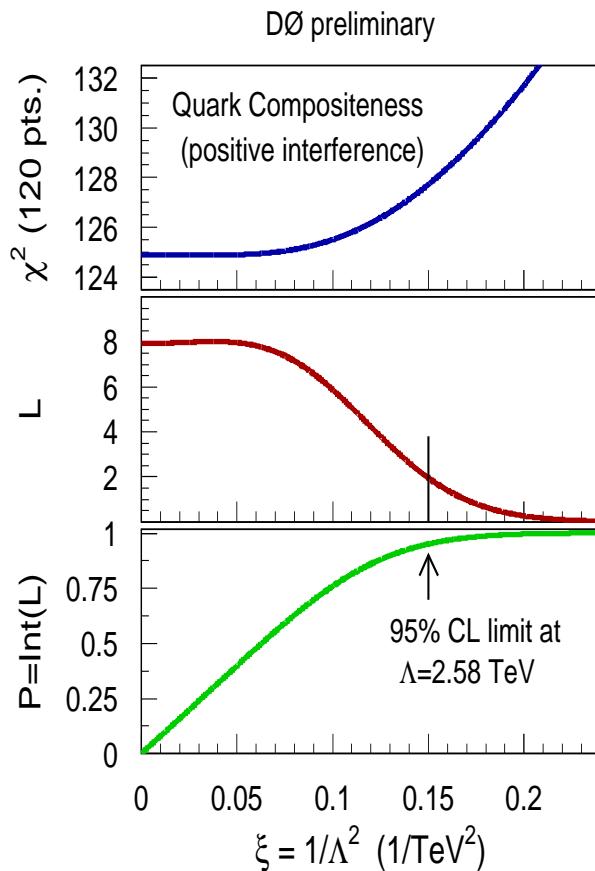


# Expected Limits

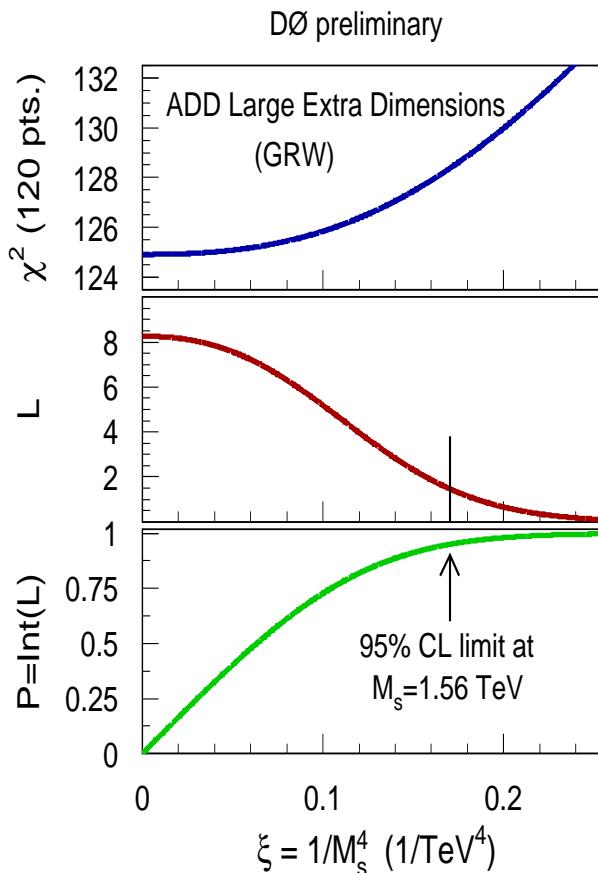
- Compare corrected-to-particle-level data against new physics signal models
  - Quark Compositeness
  - Large Extra Dimensions
  - TeV-1 Extra Dimensions
- Expected Limits



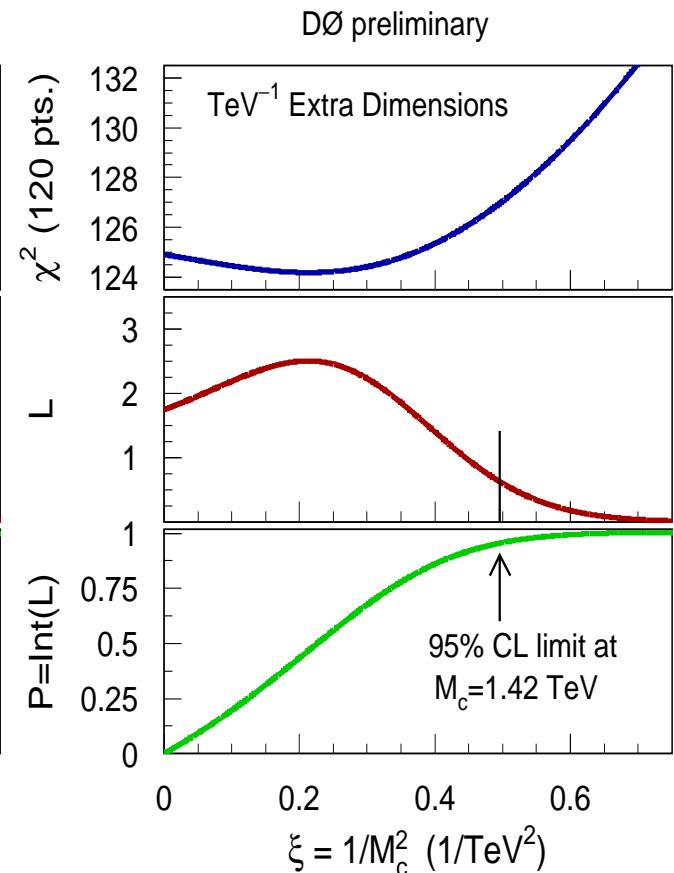
# Limits from DØ's Dijet Search



**most stringent limit**



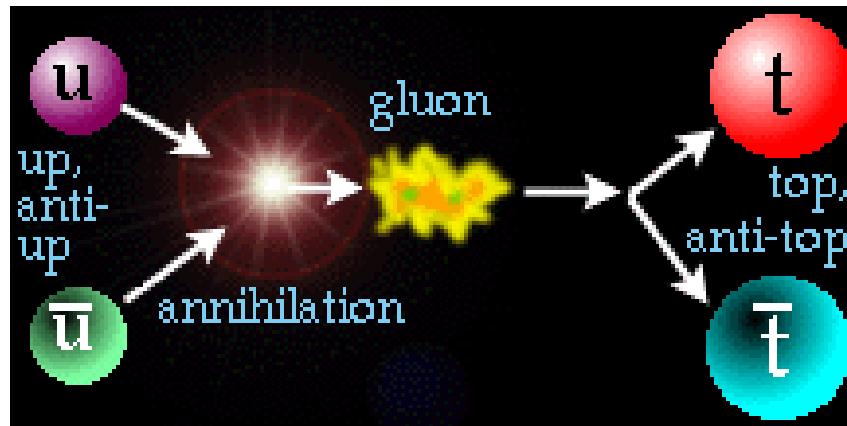
**most stringent limit  
from a single process  
from a hadron  
collider**



**strongest limit from a  
hadron collider**

# Search for resonances in ttbar events

- Is this the only mechanism by which the ttbar events are produced ?

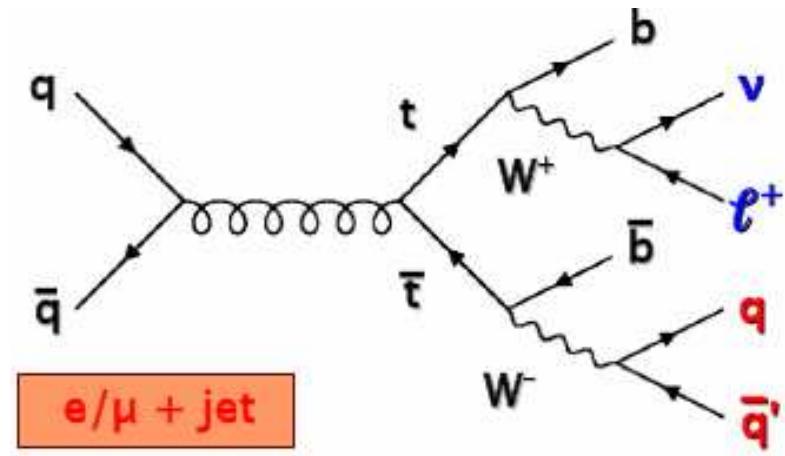


- A yet unknown neutral heavy particle (heavier than the top quark) may decay preferentially into ttbar pairs
- This would add a resonant component to the SM ttbar spectrum:  
a bump in differential cross-section  $d\sigma/dm_{ttbar}$
- An example : new strong gauge force coupling to 3-rd generation  
 $\Rightarrow$  heavy resonance Z'

# DØ ttbar Resonance Search Event Selection

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- Select “Lepton plus Jets” ttbar events
  - Isolated high PT electron or muon
  - Missing transverse energy
  - Three or more leading jets
  - One or more jets b-tagged

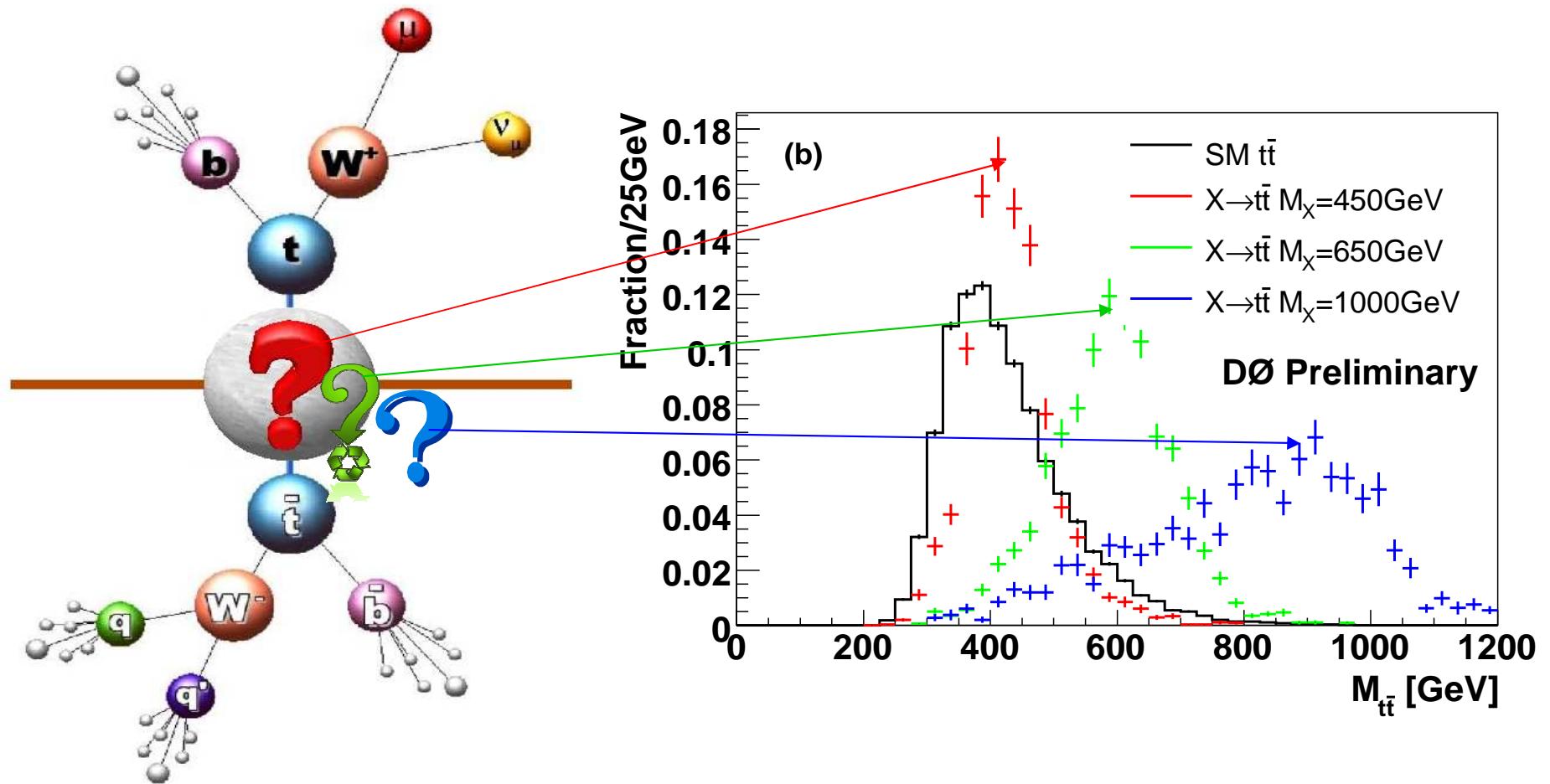


- Reconstruct ttbar mass directly (no constraint fit)
  - neutrino momentum components

$P_x, P_y$  – components of missing transverse energy

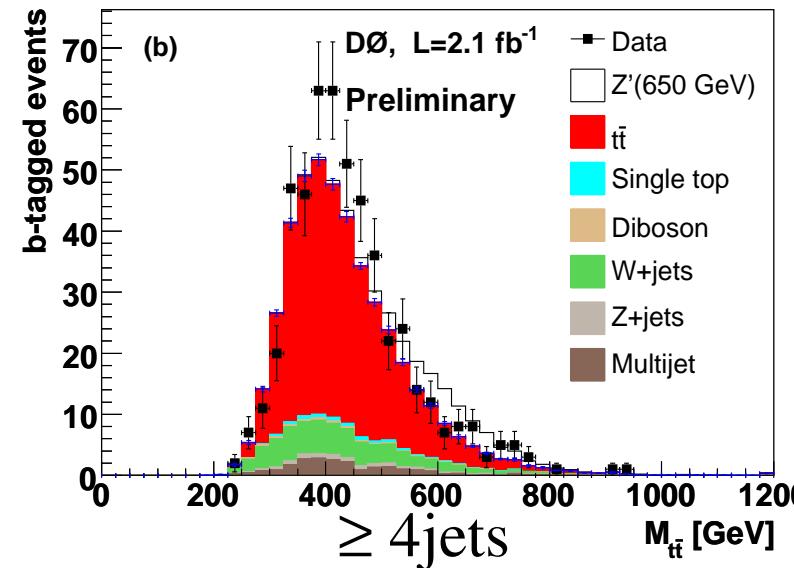
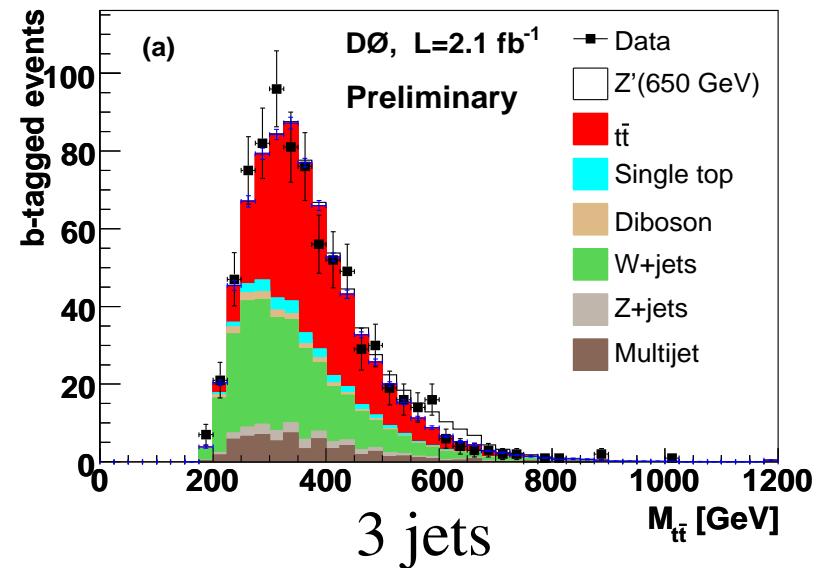
$$P_z \text{ from } M^2(W) = (p_\nu + p_{\text{lepton}})^2$$

# Reconstructed ttbar invariant mass spectrum



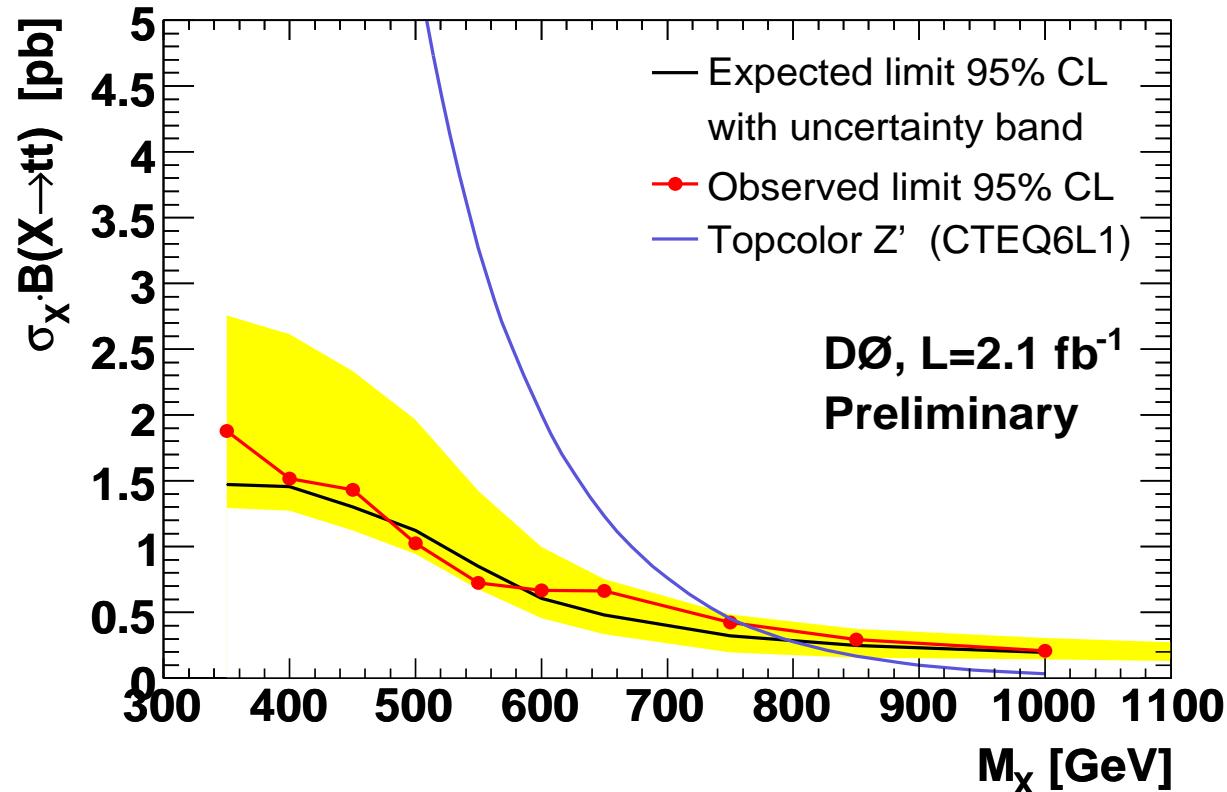
# Top Pair Invariant Mass

- Backgrounds:
  - ttbar
  - Z + jets
  - single top quark
  - diboson
  - W+jets
  - multijet
- Event yields ( $\geq 4$  jets)
  - 505 observed events
  - 344 expected from ttbar



# DØ Results of ttbar Resonance Search

- Signal model: high mass  $Z^0$ , width = 1.2% of the mass
- No interference with the Standard Model ttbar production
- Set limits using Bayesian approach



Exclude leptophobic  $Z'$  up to 760 GeV (expected 800 GeV)

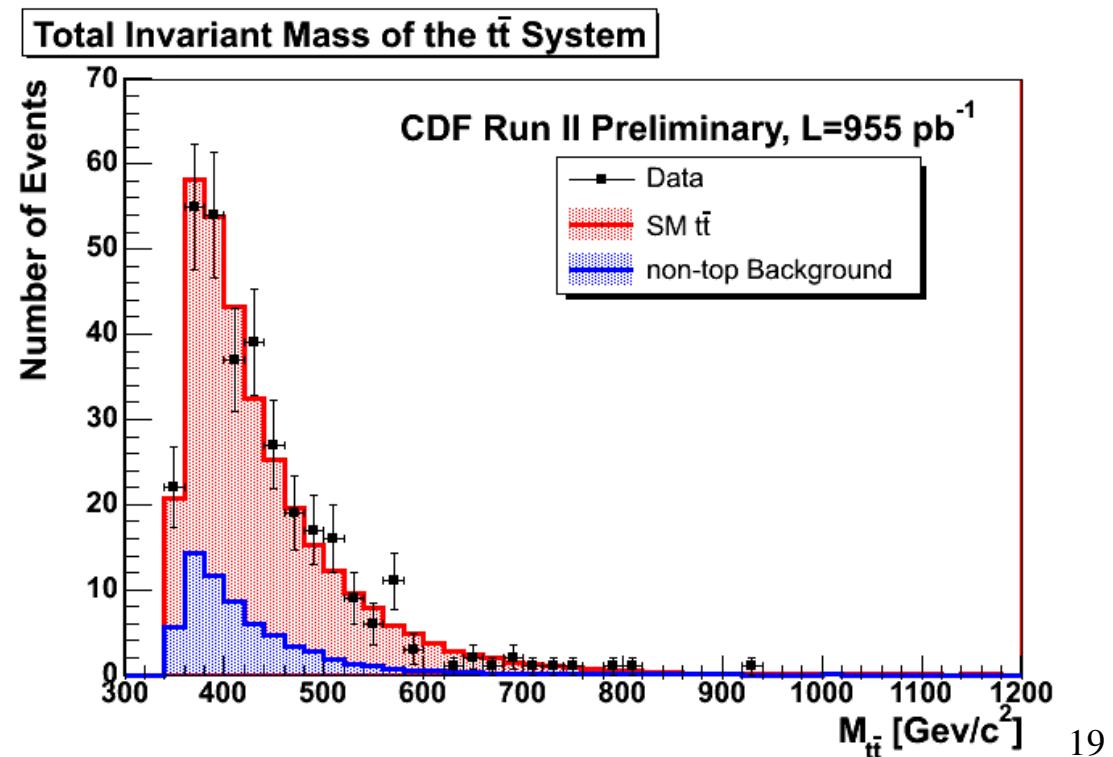
# CDF's (template method) ttbar Event Selection

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The data sample is standard b-tagged top mass selection:

- Central lepton and missing  $E_T$
- 4 jets, at least one b-tagged
- 347 candidate events of which  $73 \pm 9$  events are non-top SM backgrounds

- $M(t\bar{t})$  -- from the  $\chi^2$  based mass-fit algorithm with top and W mass constraints
- final sample of 327 candidates.



# Signal Modeling, Results

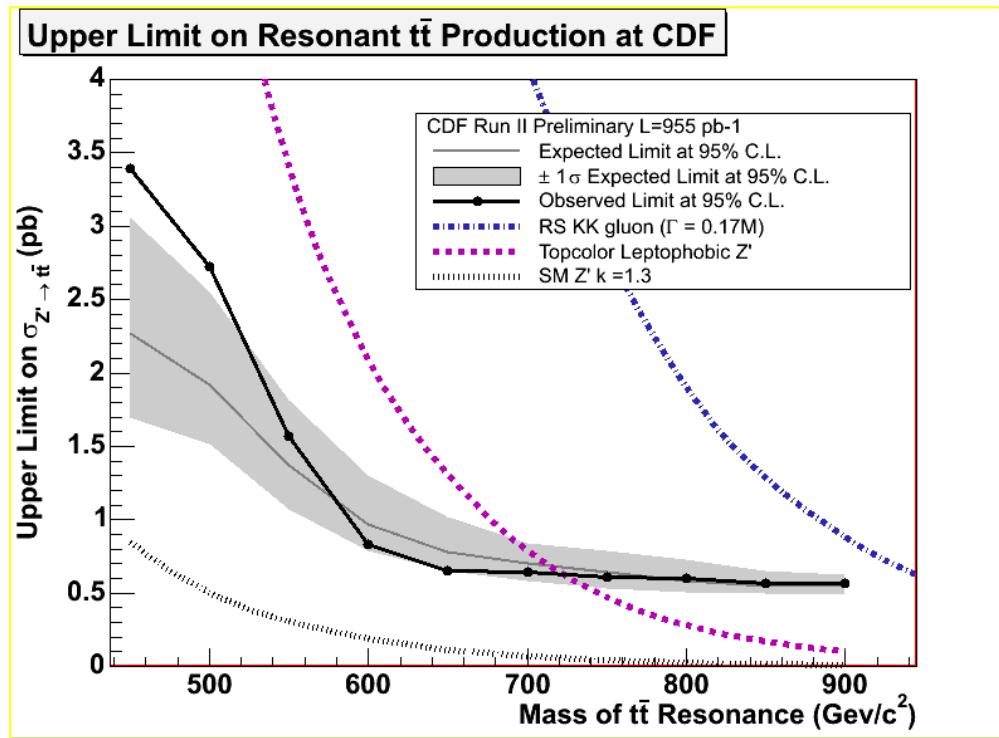
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- Same signal model as in DØ analysis  
⇒ shape is totally dominated by resolution and combinatorics
- No evidence for resonances
- set 95% CL upper limits by integrating to the  $Z'$  cross section  
which gives 95% of the area of the posterior likelihood function

# CDF's ttbar Analysis (template method)

## Results

- Same signal model as in DØ analysis  
⇒ shape is totally dominated by resolution and combinatorics
- No evidence for resonances
- set 95% CL upper limits by integrating to the  $Z'$  cross section which gives 95% of the area of the posterior likelihood function

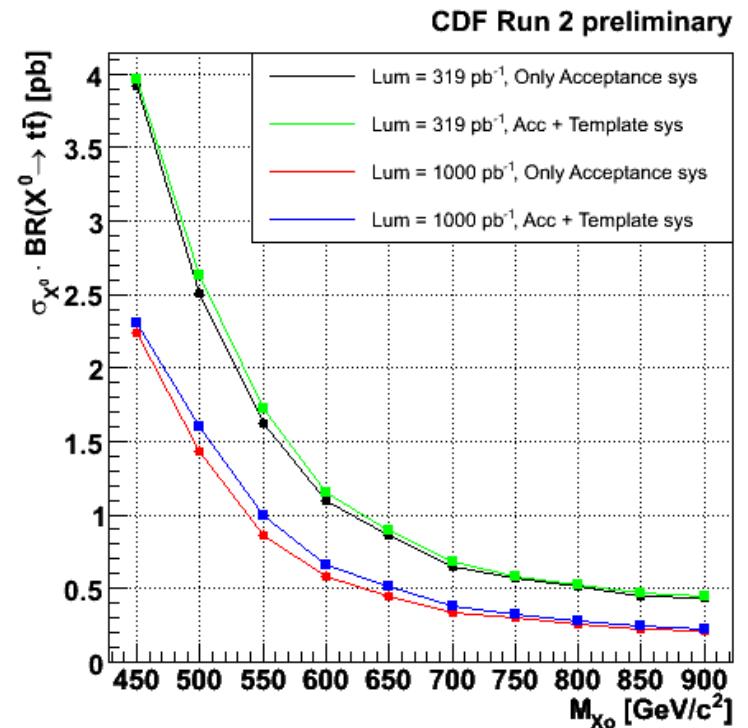


Template	Expected limit (956 pb <sup>-1</sup> )	Data Limit (956 pb <sup>-1</sup> )
$M_{Z'}=450$	$2.27^{+0.79}_{-0.57}$	3.39
$M_{Z'}=500$	$1.92^{+0.63}_{-0.40}$	2.72
$M_{Z'}=550$	$1.37^{+0.45}_{-0.30}$	1.57
$M_{Z'}=600$	$0.97^{+0.33}_{-0.18}$	0.83
$M_{Z'}=650$	$0.78^{+0.24}_{-0.13}$	0.65
$M_{Z'}=700$	$0.70^{+0.14}_{-0.12}$	0.64
$M_{Z'}=750$	$0.64^{+0.15}_{-0.11}$	0.61
$M_{Z'}=800$	$0.58^{+0.15}_{-0.07}$	0.60
$M_{Z'}=850$	$0.55^{+0.10}_{-0.05}$	0.57
$M_{Z'}=900$	$0.55^{+0.08}_{-0.06}$	0.57

# CDF's Matrix Method ttbar Analysis

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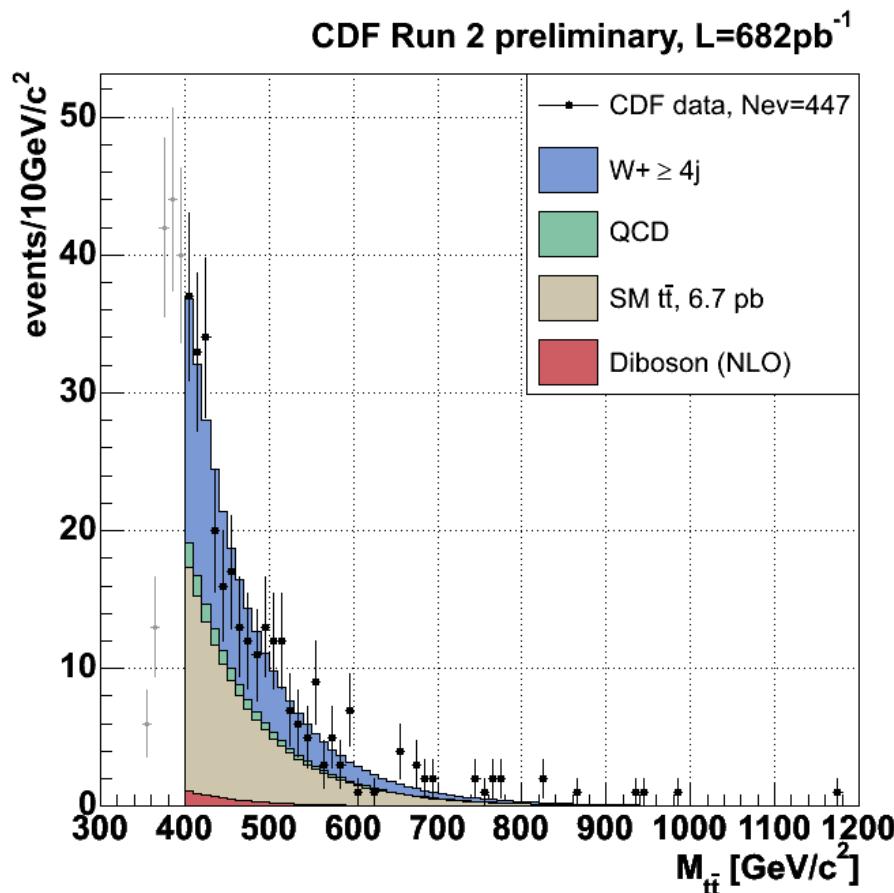
- Event selection very similar to previously described analysis
- Use matrix-element technique to reconstruct  $M(t\bar{t})$  in each event
- Establish an a priory sensitivity of the reconstruction algorithm
- 1000 simulated experiments in the null hypothesis  
⇒ Expected 95% C.L. upper limit on the cross section for resonance production assuming SM only



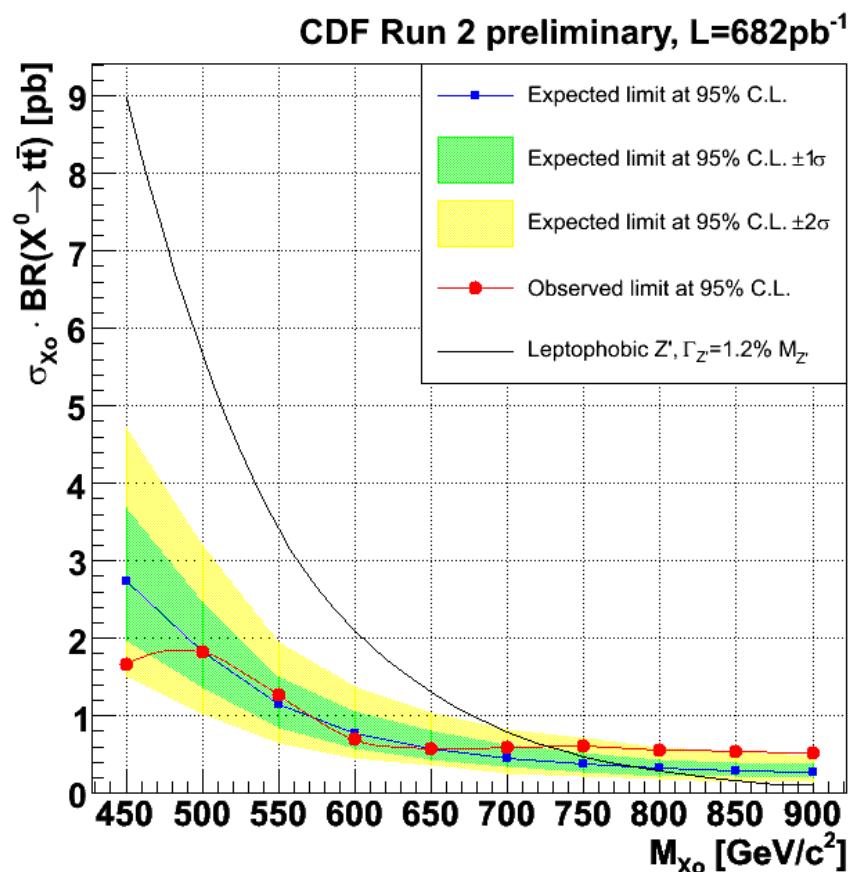
# CDF's Matrix Method ttbar Analysis

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$M(t\bar{t})$  distribution from data  
vs expected SM background  
in the  $> 400$  GeV search region



## Results



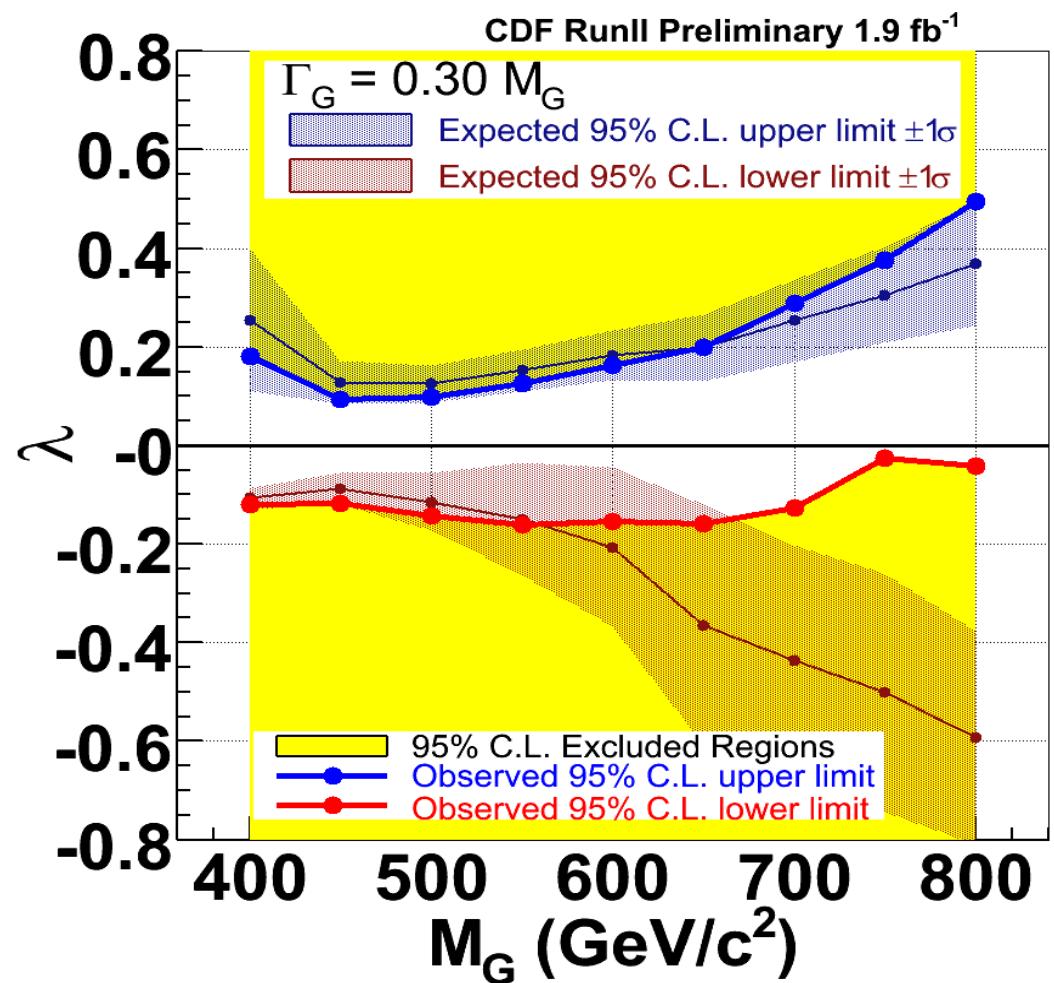
# CDF's Dynamic Likelihood Method ttbar Analysis

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- Search for the new color-octet particle **Massive Gluon**
- Three parameters : mass, width, and coupling strength
- The SM  $q\bar{q}$ →ttbar process and the  $q\bar{q}$ →Massive Gluon→ttbar interfere
- Dynamical Likelihood Method is used to reconstruct the event-by-event top pair invariant mass.
- The reconstructed data top pair invariant mass distribution agrees with the standard model expectations in the explored mass and width range

# CDF's Dynamic Likelihood Method ttbar Analysis Results

- Unbinned likelihood fit by scanning the mass and width of massive gluon to extract the coupling strength
- Fitted coupling strengths are consistent with the SM prediction
- Set limits on the massive gluon strength of coupling.



# Summary

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- Presented results of searches for new physics at CDF and DØ detectors at Tevatron proton-antiproton collider in the dijet and ttbar channels
- Dijet and ttbar data available at Tevatron allow to tackle exciting questions of modern high energy physics
  - are there yet undiscovered particles and forces ?
  - do top and anti-top form a short-lived bound state before decaying ?
  - do quarks have sub-structure ?
  - are there spatial extra dimensions ?
- A lot of hypotheses tested and parameter ranges excluded
- No evidence of new physics yet
- Stay tuned for new results as we collect more data !